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# A study on Methods of Damping in Sports Equipments

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***Abstract*: This study focuses on the need for vibration damping in various sports that include hand held equipment and deals with Impact loads (Tennis, Golf, Cricket, Pole Vault, and Badminton). Sports in these days draw huge crowd in turn huge money and the perspective has changed from hobby to profession. Many professional sports are highly competitive where millions of dollars depend on reactions in one-tenth of a second or a centimeter variation. To provide a player with this kind of precision, the equipment they use must react as per the instincts of the player without causing him/her discomfort. This is where damping technology plays a major role. This study also sheds light on different methods of vibration damping and how such a method was inculcated into the field of sports.**

***Keywords:* Sports, Vibrations, shocks, Damping.**

## I. INTRODUCTION

Modern sports is an ever developing field. As Science and Technology has been making an impact over field of sports, competition between players is rising everyday. Sports is now a Billion dollar Industry that banks millions of dollars of investment over results that occur in a fraction of a second or a centimeter's variation[1]. Earlier sports was a hobby, recreation and localized to a region. As they gained popularity, the players needed more from their equipment that the traditional designs could not provide. Equipments were designed to react as per the instincts of the player without causing him/her discomfort. The bats were made lighter, their operation were better understood, and better designs gave better performance ranges. The advancement in reducing the weight of the bat, made the vibrations and shocks that the bats transmitted became unpleasant[2]. This is where damping technology plays a major role. Since many close contact sports deal with impact loads that act in less than a second, and the player can only deflect a fast moving object's path to his desired direction. In early days of sports, all hand held equipment were made using wood, which limited the operating parameters of the equipment. It was bulky, difficult to operate and limited the versatility of the player. Without any knowledge about vibration damping the players faced a lot of difficulty in handling the ball, with an high chance of injuring the player[2]. With rapid advancement in material science, application of composite materials brought the games into a competitive sphere. Composite materials and light weight metals largely decreases the weight of the equipment and helps the sportsman to perform better. Lighter equipment are more responsive and have increased durability when compared to traditional wooden equipment. But with the added advantage of weight reduction, there was the issue of huge vibrations and shocks the players to endure which made it really difficult to perform with the desired accuracy.

The primary property that a material must possess to become a good damper is viscoelasticity. It is a property in materials where the materials exhibit elastic and viscous characteristics when they are undergoing deformation. Shape memory alloys(SMA's) also act as dampers. The body defects such as dislocations, phase boundaries defect and grain boundaries act as energy absorbing elements. The slip between boundaries of phase and grains do provide some degree of movement thus absorbing energy making it a damping property. Advancements in composite materials and nanotechnology has made improvements in damping hand held equipment from simple elastic coverings to complex filler materials [2] which will be dealt in detail further. Now it is established that damping is a necessity for the better performance and effectiveness in a hand held equipment. To establish damping, we need to analyze the weight aspect and placement of dampers. There are two methods of damping in general, Passive damping and Active damping.

A. ***Passive damping***:

It is method that uses the inherent property of the material used to provide energy dissipation and energy absorption. Materials that exhibit such properties are known as visco-elastic materials. The materials that exhibit both viscous and elastic property when subjected to a force is known as visco-elastic material [3].

B. ***Active damping:***

It is the method that uses sensors and actuators to induce a energy absorbing activity using pizeo-electric dampers to actuate the energy absorption process. The pizeo-electric dampers provide electric signals that actuate the damping property in the material. Such technology is used to actively reduce vibrations, often applied in professional sports.

In this study we will be briefly discussing on Passive methods of damping as it is easy to implement and is cost effective materials used for damping.

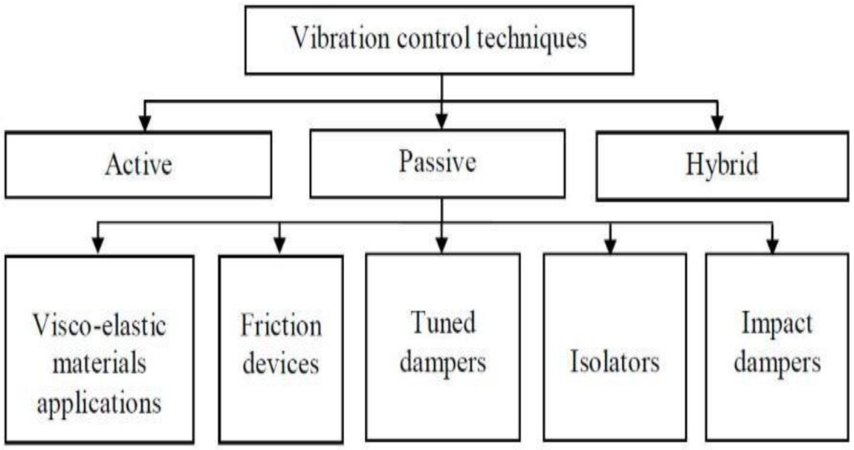



**Figure 1- Classification of Vibration Damping [8].**

## II. MATERIELS USED FOR DAMPING

A. ***Rubber:***

Rubber is the most common material that is used for vibration damping. It is obtained from natural sources, and found its way into grippers and hand held items perceived to provide comfort long before vibrations and its reduction was better understood. It is a polymer that has the best visco-elastic property. Polypropylene\ Butyl rubber blend polymers, which are extensively used in damping tennis bats and cricket bats are made out of rubber [2].

B. ***Metals and alloys:***

Certain alloys called as shape memory alloys (SMA's), and Ferromagnetic alloys are used as vibration dampers. Ferromagnetic alloys provide damping by magneto-mechanical mechanism (movement of magnetic domain along the phase boundaries). Shape Memory effect refers to the ability of the material to transform to a phase having twinned microstructure that, after subsequent plastic deformation, can return the metal to its initial phase [3].

C. ***Polymer materials:***

Due to the viscoelastic behavior exhibited by certain polymer compounds, it finds large applications in damping sports equipment. Rubber although being a good damping material itself, has low stiffness and modulus of elasticity values. To compensate this and to enhance the performance limitations of the equipment polymers are blended with natural rubber. Polymers that are used in vibration damping include polytetrafloroehtylene (PTFE), Polypropylene/Butyl rubber blend, urethane interpenetrating polymer blend.

D. ***Composite Materials:***

Certain fibrous structural composites are used for vibration damping. Due to the interpenetrating mesh of fibers that create a hollow spacing even in between the resin matrix provides the damping mechanism. Also with the rise in temperature (eg.50$^{o}$C) interlayer of the composite degrades and stiffness of the matrix reduces significantly.

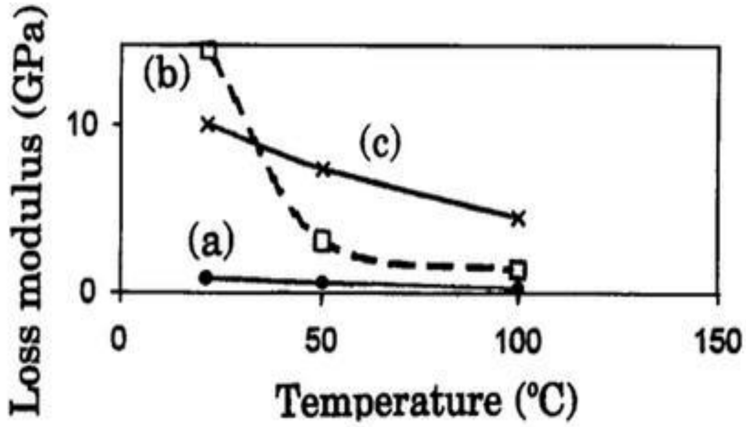


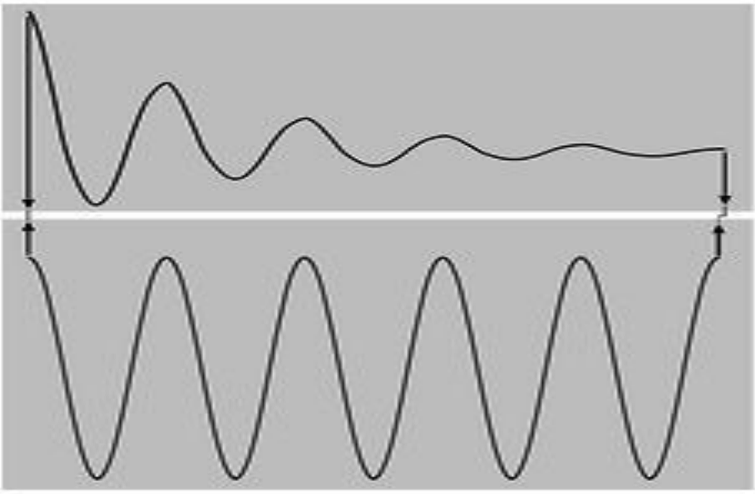

**Figure 2- shows a graph showing variation of loss of modulus with temperature. A composite without interlayer (a) shows least change to temperature, while a composite with viscoelastic interlayer (b) has least loss of modulus with increasing temperature[3].**

## III. DAMPING METHODS

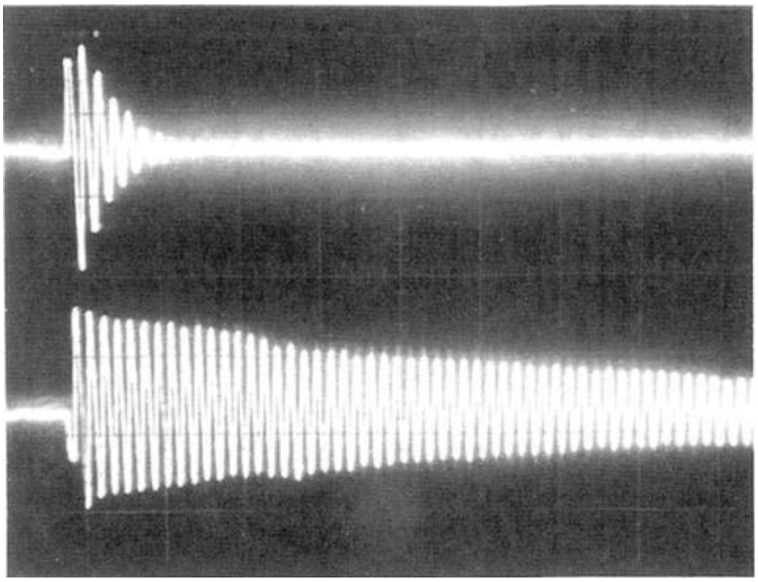
Every sport shows a different style, and operates on different rules. Hence, every sport has its own uniquely designed equipment that works best under the conditions set by the sport. Damping is a method of reducing vibrations induced in the equipment. It cannot be done in one standard way, but varies from sport to sport.

***A. Addition of Dampers:***

It is the most common way of reducing vibrations. The science says wrap the area with dampers where most vibrations are felt. It is still applicable in sports like cricket, Baseball and Tennis. It involves a projectile being thrown at large speeds at the player and the player deflects the path of the object using a “bat”. This phenomenon is an example of simple momentum transfer. As the bats got lighter, the impact force exerted by the ball onto the bat created large vibration forces at the center that was felt by the player. The dampers absorb this unpleasant force before the wrists of the player feel it. The bat also needs to deliver maximum momentum transfer to the ball, and the condition to achieve this is to maximize the weight at the wrist end and minimize the weight at the free end. Adding the dampers at the wrist end prevents the transmission of vibrations and also increases the weight at the wrist end [10]. Many racket manufacturers claim that one of the virtues of their racket is that vibrations damp out quickly. The vibrations of a tennis racket that seem to be particularly annoying are caused by the first harmonic mode of oscillation. This mode has a node near the center of the head, a node near the top of the grip, and antinodes at the tip, butt end, and near the throat. The frequency of this mode of oscillation runs from about 120 Hz to 200 Hz, depending largely on the stiffness of the racket frame since there is little variation in mass from one racket model to another. The damping time (the time for the amplitude of the oscillation to fall to half its value) was tested by experimentation for different frequencies for two Prince Classic rackets, one with damping element and gripper and another without damping element and gripper. This was done by fixing a small, light Kynar vibration sensor (Pennwalt Corp., P.O. Box C, King of Prussia, PA 19406) to the throat of rackets with double sided tape and suspending the rackets from the node near the top of the grip to simulate normal holding position. The rackets were then struck on the strings near the tip, and the output from the Kynar sensor was observed on an oscilloscope. The traces were photographed, enlarged, and then measured to determine the damping time. [4]. While the damping time for the bat without damping element was of the order 180ms, the magnitude was shorter in the racket with damping element of the order 70ms.These data show that the time needed for the amplitude of the oscillations to damp to half its value depend strongly on how tightly the racket was gripped and the magnitude of vibrations absorbed by the damping element. [4].



(a)



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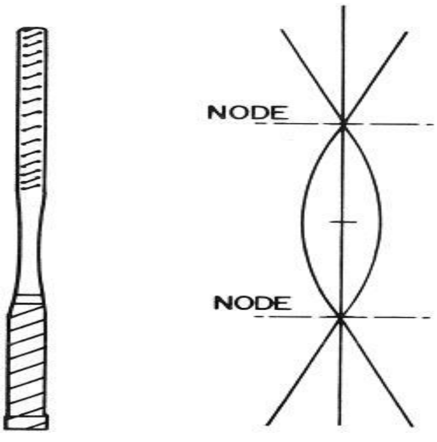



(c) **Figure 1 — The locations of the nodes of an oscillating tennis racket.**

**Figure 3- (a) shows the pictorial waveform of vibrations in its free state and when dampened. (b) shows the dampened waveform when the bat with damping was applied with force and the other waveform is the one without damping element. (c) shows the positions of nodes in tennis bat[10].**

***B. Damping through Bat Material:***

Sports like pole vault, Javelin throw require very long shafts that either required to be thrown at a distance(Javelin) or used to propel the person himself at a distance above the ground(Pole Vault). They share very common designs and operating parameters. Since the vibration and shocks are transmitted at the length of the body, it is impractical to wrap the entire length of the pole with damping element. Hence, materials with damping property are itself used to fabricated the equipment. Ideally designed as a shaft, its function is to absorb as much as force exerted by the player. Javelin throw requires the player to run at a distance, gain as much kinetic energy possible and transmit the same to the javelin. The sway that the javelin is under when the player runs makes it very uneasy to grip it since the player holds it in the end to transfer maximum energy on the pole. This is where damping is required. Reinforced Carbon fiber is used along with s-glass / e-glass material.[6] The composition of S-Glass and E- Glass are shown in Table 1.

**Table 1: composition of s-glass and e-glass material [6].**

| **Material** | **Composition** | Percentage |
|---|---|---|
| S-glass | Silicon Di Oxide | 64-66% |
| | Aluminium di oxide | 24-26% |
| | Magnesium di oxide | 9-11% |
| E-glass | Calcium Oxide | 16-25% |
| | Aluminium Oxnide | 12-16% |
| | Boron | 5-10% |

In the case of pole vault, the player exerts his weight at the free end and a reaction force created at the fixed end of the pole propels the player to a height. The pole needs to be light, have good stiffness and modulus of elasticity. [12] Also there are vibration forces that act along the length of the pole when the player is propelled by the bat that can damage the player's wrists and elbow. To prevent the damage to the player and the failure of the pole, the pole is designed to make it lighter and vibration free at the same time.

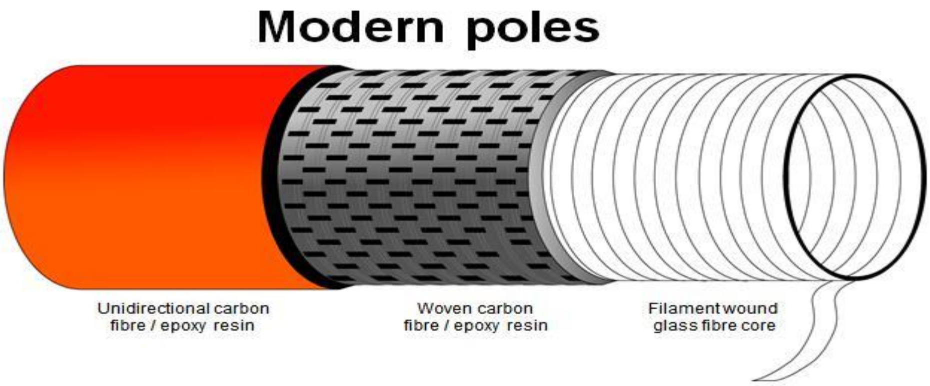
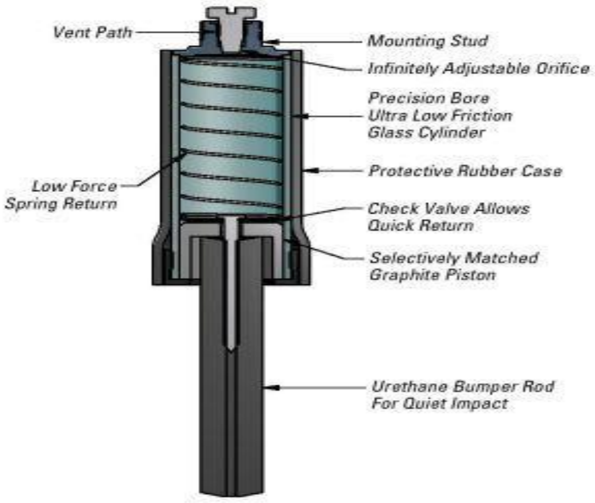



**Figure 4: sectional view of a pole vault[15].**

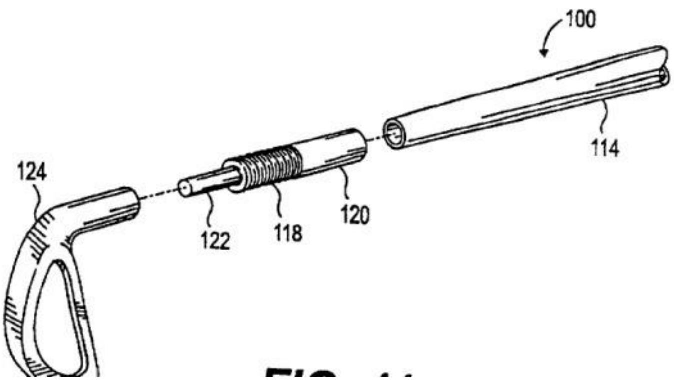
The pole is made of three layer composite material. The objective of this is to compound the function of each layer to create a shaft that exhibits properties of all the three layers. The pole is made of a glass fiber core that is wound like a shaft. The glass fiber shows good stiffness and modulus of elasticity, which is helpful to prevent the pole from failure. A Carbon fiber resin acts like the filler material that makes the second layer of the shaft. The carbon fiber is a good visco-elastic material and absorbs any unwanted forces transmitting along the length of the bat. The final outside layer is made of unidirectional Carbon fiber/Epoxy resin. It is a unidirectional composite that's sole function is to transmit forces and vibrations alike along the length of the shaft. With the properties of damping and good stiffness, the pole vault is a good example for damping equipment through Bat Materials.

***C. Vibration Damping Devices:***

Certain sports require additional damping devices that facilitate vibration damping before it reaches the handle. A vibration-damping device can be mechanical or electrical in nature. In this case we only discuss about the mechanical devices. It consists of a hollow cylinder that is filled with a visco-elastic material. A piston that exerts the force from impact of the bat to the visco-elastic material, a bumper rod that transmits the forces and reduces the impact.




(a)

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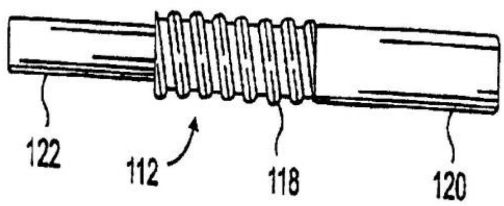


(c)

**Figure 6- Placement of cylindrical damping device in golf stick [13].**

***D. Harmonic Dampers:***

Harmonic Dampers finds applications in rotatory elements of any machine. It is used to dampen the extra torque that might hinder the operational rpm of a rotating element. It also finds application in Archery to dampen vibrations when the arrow is shot, thus increasing the accuracy. Typically, compound bows are configured so that a bowstring may be easily pulled without using a large force and arrow-shooting power is increased during shooting, by using an effect of a cam or wheel, to thus result in a fast speed of an arrow with very strong power and greater force driving it. The basic concept in archery is to achieve higher accuracy shots,[9] larger arrow forces makes them to cut through the air faster which minimizes the drag from the wind [11].


**Figure 5- Cross section of cylindrical damping device [12].**

Golf finds the application of damping devices. When the club comes in contact with the bat, the club end comes under vibrations. These vibrations come out of phase with the vibrations at the shaft; hence they cause discomfort and uneasiness while hitting the ball. To prevent this, additional damping is required to increase the stability of the bat, and increase the accuracy of the shot. The vibration-damping device added in golf clubs is added into the shaft with any kind of water-based adhesive to keep it in one position. The bats are predominantly divided into three types “irons”, “putters” and “woods” depending on their impact to the ball. The golf club has a sweet spot at the center of the bat, which when missed induces torsional and vibrational forces that are unpleasant. Placing the damper as near to the club as possible minimizes the dispersion of such forces to the hand. Hence, the bat can be held as firmly as possible that ensures a better aim, achieving the desired distance with better accuracy.

When the bowstring is pulled in the prior art compound bow, the lower and upper pulleys and are rotated to thereby wind and pull the cables. When the bowstring is released in a let-off state, an arrow obtains a strong driving force while the bowstring returns to an original position instantaneously by a strong elastic force of the bow. As described above, while the bowstring returns to an original position when the arrow is shot, vibrations are generated from the bowstring that is formed between the upper and lower pulleys. Such vibrations are ultimately transferred to the handle to thereby cause a problem that degrades the accuracy of the arrow [9]. In order to solve such a problem, a bowstring support bar for supporting the bowstring is provided at the lower side of the handle. One end of the bowstring support bar is coupled to the lower side of the handle, and the other end thereof is bonded to a contact rubber that supports in contact with the bowstring.

When the bowstring returns to an original position at a let-off state, that is, at a firing state, the bowstring is in contact with the contact rubber of the bowstring support bar, thereby damping the vibrations of the bowstring. Thus, such vibrations generated from the bowstring can be attenuated to some extent even in the case of the compound bow. However, vibrations transmitted to the handle cannot be removed satisfactorily so that a user can hardly feel the vibrations.

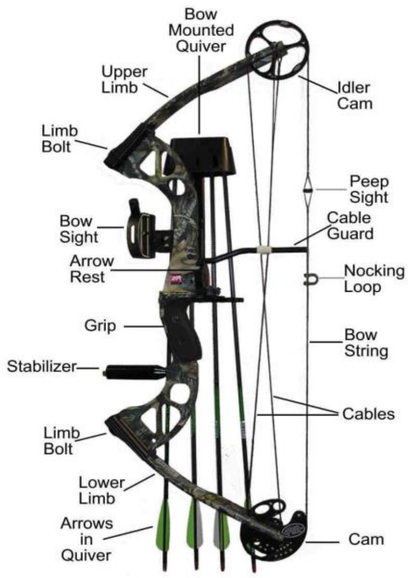


**Figure 8- Parts of a compound bow.**

***E. Particle Damping:***

Particle damping is a technique of providing damping with granular particles. The particles absorb kinetic energy through particle- to-wall and particle-to-particle frictional collisions. Because of its extreme simplicity, high effectiveness and low cost, it has a tremendous potential for vibration and noise suppression in a broad range of application. Therefore, they are suited for applications where there is a need for long service in harsh environments. Applications of particle damping founds in weightless environments of outer space, in aircraft structures, to attenuate vibrations of civil structures, in tennis rackets etc. [8] Many users prefer that sporting equipment minimize levels of shock, vibration, and airborne noise. A few factors that affect the performance of the player involve psychoacoustic responses from the equipment, thus gives the need of maximum damping of vibrations [7]. Particle dampers, also known as shot dampers or granular-fill dampers are passive damping devices. The principle behind particle damping is the removal of vibratory energy through losses that occur during impact of granular particles, which move freely within the boundaries of a cavity attached to a primary system. Particle damping with suitable materials cane performed in a wider temperature range than most other forms of passive damping. Therefore, it can be applied in extreme temperature environments, where most conventional dampers would fail. *A.* The damping efficiency of particle damping depends on cavity dimensions. When the optimum dimensions of the cavity are large, the optimum cavity may not be attached from practical design point of view. In such a case, the damper performance is retained when particle dampers are replaced by multi-unit dampers with a moderate number of small cavities. Particle damping technology is a derivative of impact damping with several advantages. The granular material is filled into a hollow shaft of a golf club during fabrication. [8] Sand and lead shot have been used as a damping treatment, the reduction in user fatigue and discomfort due to reduction in "sting" associated with every hit [7]. Sand and Lead shots cost effective way of reducing vibrations and shock forces in the golf drives, the only discomfort being an increase in its weight. A need thus exists for a low-density, granular material whose vibration damping properties are substantially insensitive to temperature, for use in sporting equipment [7]. Ideally, such a material should be lightweight, with good damping properties, ease of manufacture, and low cost. There are many materials which fit in the above set conditions. An ideal granular material must have a bulk sound speed less than 90m/s and must have a low density (less than 1000kg/m3). The table 2 shows material granules that can be used for vibration damping. This method of damping, sometimes called particle impact damping (PID) is often thought to be more efficient than traditional methods of damping, such as placement of viscoelastic layers over surfaces of structures. Damping by granular particles occurs because part of the energy of vibrating structures is passed to the granular particles that collide with each other. As a result, their kinetic energy is dissipated into heat due to frictional losses and inelastic collisions. The advantage of particle damping is its implicit simplicity and its ability to work over a broad range of frequencies. It also has the advantage of not being affected by high temperatures, and it is easy to install without affecting the structural integrity [9].

**Table 2:materials that can be used as Granular Dampers.**

| *Lodengraf™ code* | *material* | *sound speed (m/s)* | *density (kg/m³)* |
|---|---|---|---|
| L-K0150 | 3M Scotchlite™ glass microballoons | 97 | 70 |
| L-E3000 | expanded polystyrene (EPS) | 96 | 11 |
| L-L4000 | low density polyethlene (LDPE) | 95 | 570 |
| L-V3000 | vermiculite | 90 | 132 |
| L-P20L80 | 20% perlite/80% LDPE | 67 | 475 |
| L-P5000R | perlite | 62 | 97 |
| L-P1500 | processed perlite | N/A | 200 |
| L-P50L50 | 50% perlite/50% LDPE | 56 | 334 |
| L-P40L60 | 40% perlite/60% LDPE | 56 | 381 |
| L-P60L40 | 60% perlite/40% LDPE | 54 | 286 |
| L-P80L20 | 80% perlite/20% LDPE | 51 | 192 |
| L-P43S57 | 43% perlite/57% sand | 37 | 931 |
| L-R0030 | 3 denier, 0.030" precision cut rayon flock | ~100 (unannealed) | ~200 |
| L-N0020 | 3 denier, nom. 0.020" random cut nylon flock | N/A | ~200 |

The result from the above experimentation showed that there are three primary factors that affect the performance of particle dampers. Effect of orientation and surface Area: A box of 30x20x10mm Aluminum container was filled with particle dampers and glued on 30x20mm side, then 20x10mm side then 20x30mm side and subjected to vibrations of varied frequency. It was seen that the surface area plays no significant effect in damping when at a frequency of 3000Hz, while damping was significantly reduced when it was subjected to a frequency of 1000Hz [8].

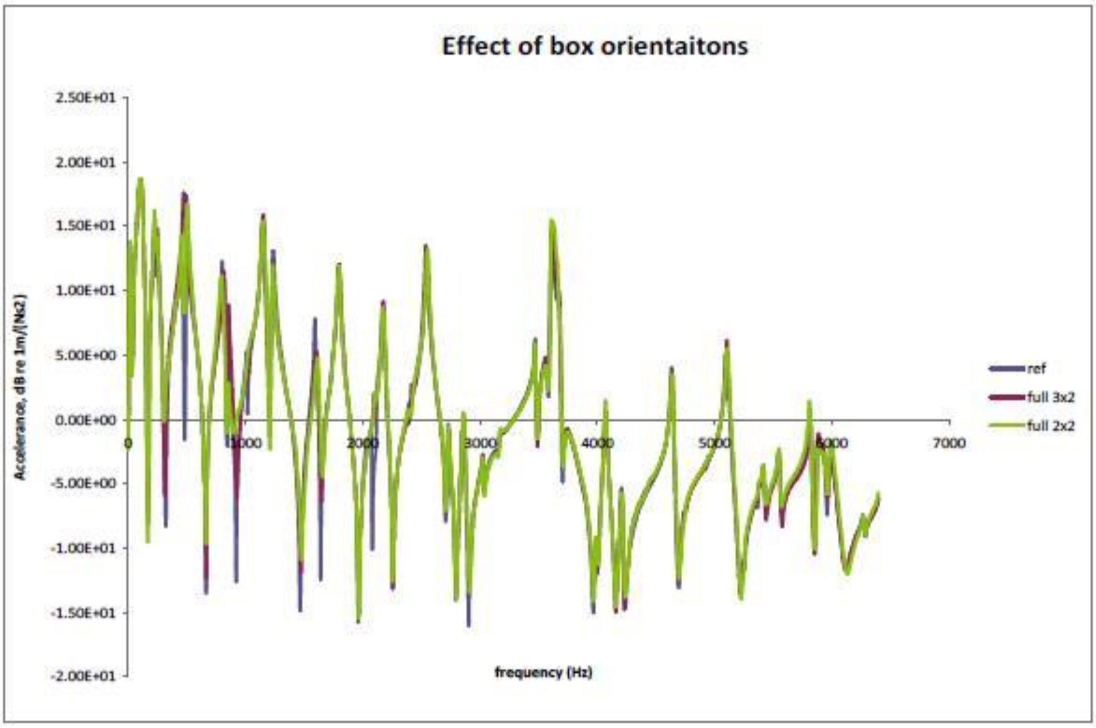


**Figure 9: Relationship between accelerance to frequency[11].**

### *F. Effect of Particle size:*

The investigation was carried out using steel ball bearing with varying sizes of 1mm, 3mm and 5mm diameter. An aluminum container was filled with all the 3 sized balls such that in each case the total mass remained the same. Weight was maintained to ensure damping by virtue of mass remained the same, and material was kept the same to ensure common density. It was expected that the box with larger particles exhibited more vibration damping as the surface area of contact was more and particle collisions for dissipating energy was more. But it was seen that 3mm diameter steel balls showed promising results than 5mm diameter steel balls, which is unexplained. Thus, we can come to a conclusion that the particles with average diameter show high damping properties [7].

## IV. CONCLUSION

This review thus briefly presents the benefits, need and necessity of vibrational dampers in sport equipment. It sheds light on how damping materials can be used to improve the performance of the player. It widens the psychological response spectrum of the player since most of the discomfort created by vibrations is reduced. It also allows designers to focus more on improving the designs by increasing the surface area of the "sweet spot" (responsible for giving the ideal shots) of the equipment. Thus a good damper does not only increases the safety of the player, but also helps improve the technologies used in sports. Yet even with all the positive aspects of vibration damping, it seems there lies many bio-mechanical issues (related to the relationship between the body and equipment) that needs to be answered. There is still scope for improvement in the rate and amount of damping which is still limited to a very specific range of materials.

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